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UTILIZATION OF SEWAGE SLUDGE FOR TERRAIN STABILIZATION IN COLD --ETC(U)
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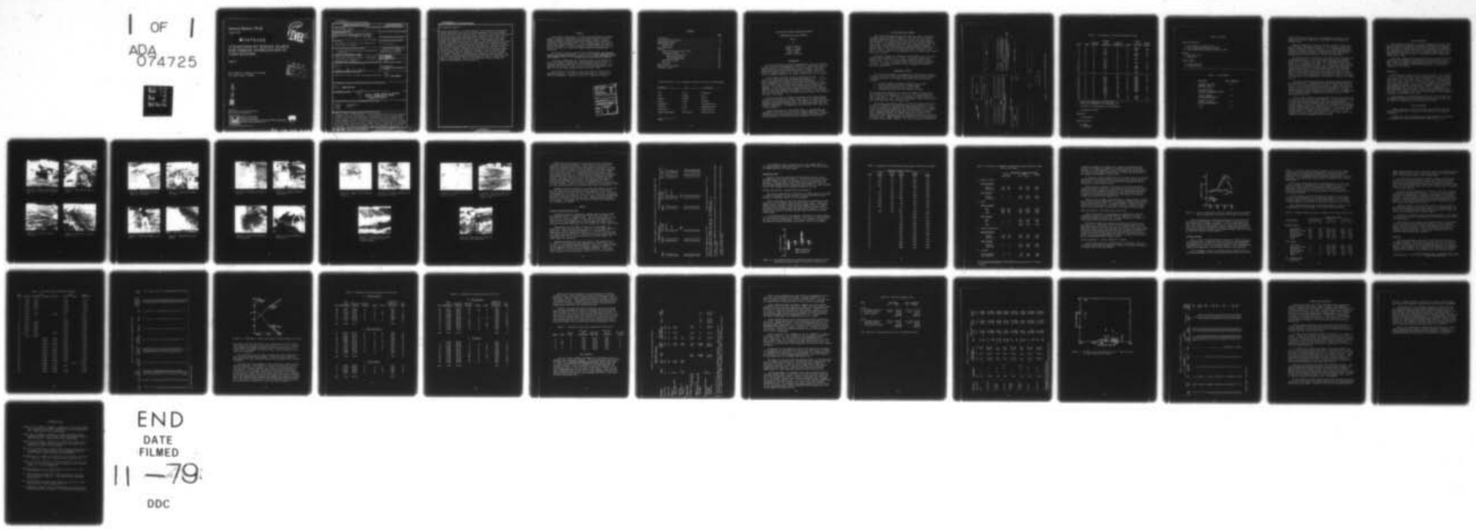

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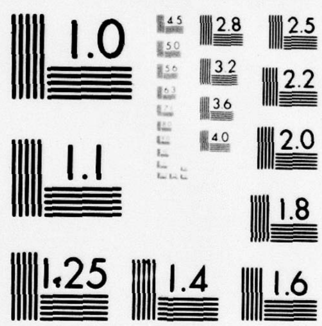

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Special Report 79-28

August 1979

UTILIZATION OF SEWAGE SLUDGE FOR TERRAIN STABILIZATION IN COLD REGIONS

Part II

D.A. Gaskin, A.J. Palazzo, S.D. Rindge,
R.E. Bates and L.E. Stanley

Prepared for
DIRECTORATE OF MILITARY PROGRAMS
OFFICE, CHIEF OF ENGINEERS
By
UNITED STATES ARMY
CORPS OF ENGINEERS
COLD REGIONS RESEARCH AND ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE, U.S.A.

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1

1. REPORT NUMBER
Special Report 79-28

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
6 UTILIZATION OF SEWAGE SLUDGE FOR TERRAIN STABILIZATION IN COLD REGIONS. Part II.

5. TYPE OF REPORT & PERIOD COVERED

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
D.A. Gaskin, A.J. Palazzo, S.D. Rindge, R.E. Bates, and L.E. Stanley

8. CONTRACT OR GRANT NUMBER(s)
12 47

9. PERFORMING ORGANIZATION NAME AND ADDRESS
U.S. Army Cold Regions Research and Engineering Laboratory
Hanover, New Hampshire 03755

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
DA Project 4A762720A896
Task 04, Work Unit 003

11. CONTROLLING OFFICE NAME AND ADDRESS
Directorate of Military Programs
Office, Chief of Engineers
Washington, D.C. 20314

17 04

12. REPORT DATE
11 Aug[redacted]79

13. NUMBER OF PAGES
40

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
9 Special rept.
Jun 75-Sep 76

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
Approved for public release; distribution unlimited.

16 4A762720A896

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)
14 CRREL-SR-79-28

18. SUPPLEMENTARY NOTES
10 David A. /Gaskin, Antonio J. /Palazzo,
Susan D. /Rindge, Roy E. /Bates
Leonard E. /Stanley

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Erosion	Stabilization
Sewage	Terrain
Sludge	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

From June 1975 to September 1976, a research/demonstration study was conducted at CRREL in Hanover, New Hampshire, to investigate the use of sewage sludge, commercial fertilizer and cultivation techniques for terrain stabilization in cold regions. Twenty-seven test plots on a 16° west-facing slope received various combinations of : 1) surface preparation (tilling, bulldozer tracking, or compacting), 2) nutrient source (sewage sludge or fertilizer), 3) mulching agent (wood fiber mulch or peat moss), and 4) tacking agent (Terra Tack III or Curasol). The plots were seeded in either the spring or fall with a CONT

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20. Abstract (cont'd)

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constant seed mixture. The effectiveness of the treatments was determined through vegetation yields and soil loss measurements. All three surface preparations effectively reduced erosion. The soil loss was 91% to 94% less than the control and average vegetation yields ranged from 3580 to 5073 lb/acre. Fertilizer treated plots had slightly less average soil loss than those treated with sludge (1.79 vs 2.21 tons/acre). The sludge treated plots, however, produced higher vegetation yields except at the first cutting of the spring seeded plots. There were only minor vegetation differences between the two mulches or between mulched and unmulched plots. However, plots with peat moss had slightly higher soil loss than plots with no mulch or wood fiber mulch. Addition of either tacking agent did not affect plant growth but did increase soil loss slightly. Treatment costs for materials plus labor ranged from \$1625 to \$4195/acre at 1978 prices (including overhead and profit). Treatments involving more variables were more expensive. The most cost-effective treatments would include fertilizer or sludge without a mulch or tacking agent. With all other variables constant, sludge was \$250/acre more expensive than fertilizer.

PREFACE

This report is the second in a series on the utilization of sewage sludge for terrain stabilization in cold regions prepared by David A. Gaskin, Geologist, Geotechnical Research Branch, Antonio J. Palazzo, Agronomist, Earth Sciences Branch, Susan D. Rindge, Physical Scientist, Geotechnical Research Branch, Roy E. Bates, Meteorologist, Snow and Ice Branch, and Leonard E. Stanley, formerly a Research Physicist, Technical Services Division, U.S. Army Cold Regions Research and Engineering Laboratory.

The work was performed under DA Project 4A762720A896, Environmental Quality for Military Facilities, Technical Area B, Source Reduction Control and Treatment, Work Unit 025, Revegetation of Terrain in Cold Regions.

The authors acknowledge the contributions made by the CRREL Detachment of the Maynard, Massachusetts, Meteorological Team, U.S. Army Atmospheric Sciences Laboratory in the collection and analysis of climatological data during the study, and by John Graham, Wayne Hannel, and Roger Winn in the study preparation and collection of data.

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CONTENTS

Conversion Factors: U.S. Customary to Metric (SI) Units of Measurement

Multiply	by	To Obtain
inch	25.4*	millimeter
foot	0.3048*	meter
gallon	0.00379	$meter^3$
pound	0.4536	kilogram
pound/acre	1.121	kilogram/hectare
ton/acre	2.240	megagram/hectare
dollar/acre	2.471	dollar/hectare
degrees Fahrenheit	$(T_{°F}-32)/1.8$	degrees Celsius

*Exact

UTILIZATION OF SEWAGE SLUDGE FOR TERRAIN STABILIZATION IN COLD REGIONS

PART II

by

David A. Gaskin
Antonio J. Palazzo
Susan D. Rindge
Roy E. Bates
Leonard E. Stanley

INTRODUCTION

A terrain stabilization research/demonstration study was conducted at CRREL in Hanover, New Hampshire, in 1975-76 to investigate the use of sewage sludge for terrain stabilization in cold regions. The 1975-76 experimental design evolved from the results of a study conducted in 1974-75 at CRREL by Gaskin et al. (1974, 1975 and 1977) on the utilization of domestic wastewater for terrain stabilization in cold regions.

In the 1974-75 study the variables tested were nutrient source (fertilizer, dewatered sludge, and primary wastewater), moisture (irrigated, nonirrigated and irrigated with primary wastewater), erosion control material (jute netting, straw tacked with a tacking compound, and no erosion control material) and vegetation (three grasses and two legumes). In the 1974-75 study 13 test plots (10 ft x 40 ft) were installed on a 16° west-facing slope with individual 350-gal. sediment traps for measuring sediment loss (Gaskin et al. 1977). A control was left bare of fertilizer, seed and erosion control material for comparison with the 13 test plots.

The data collected on sediment loss during 1974-75 indicated that sludge was acting both as a nutrient source and as an erosion control material (net) by reducing soil loss. The sludge, fertilizer and primary wastewater treatments averaged 150, 814 and 982 lb/acre soil loss (dry weight), respectively. In comparison, the control plot had a soil loss of 34,531 lb/acre.

Based on the results of the 1974-75 study, a new experiment was designed for 1975-76 on the utilization of sewage sludge for terrain stabilization after construction in cold regions. The design, construction and results of the 1975-76 study are discussed in this report.

SITE LOCATION AND CLIMATE

The research/demonstration site used for this study is located on the CRREL property as shown in Figure 1. The test area is located on sediments deposited during the Pleistocene epoch into former glacial Lake Hitchcock. The natural soil in the test area (in plots marked as 1-14 in Fig. 1) is wind-blown fine-grained silt classified ML under the Unified Soil Classification System (U.S. Army Waterways Experiment Station 1960). Gravel fill had been intermixed with the natural soil in plots 1-7 and 14. The soils in plots 15-27 were a mixture of sand, gravel, and silt dumped over the embankment from the parking area directly above the test area.

The Hanover climate is classified as the Woodland type of the Cool-Temperate Zone (Landsberg et al. 1965). The 30-year normal yearly precipitation is 37.3 in. with the normal maximum occurring in July (4.18 in.) (U.S. Dept. of Commerce 1973). The normal mean temperature is 44.8°F. The highest and lowest recorded temperatures are 101°F and -40°F respectively.

EXPERIMENTAL DESIGN

This study was designed to investigate the effectiveness of several treatments for erosion control and slope stabilization in cold regions. Treatments consisted of a constant seed mixture and the following variables:

1. Surface preparation (tracked, compacted, or tilled)
2. Nutrient source (fertilizer or sewage sludge)
3. Mulch (wood fiber mulch, peat moss, or none)
4. Tacking agent (Terra Tack III, Curasol, or none).

The treatments were applied to 27 test plots (plots 1-14 measured 10 x 40 ft and plots 15-27 measured 8 x 40 ft) on a 16° west-facing slope (Fig. 1 and Table 1). Each plot had a sediment collection tank at its base to measure soil loss. Plots 1-14 had 350-gal. tanks, 15-26 had 110-gal. tanks, and plot 27 had a 320-gal. tank.

The constant seed mixture used on all plots except the controls (6, 13 and 24) consisted of one legume and three grasses (Table 2). This mixture was selected to combine certain desired properties of the chosen species to obtain rapid germination and soil stabilization in a climate with a limited growing season (averaging 133 days) and cool temperatures. Birdsfoot trefoil, the legume, was selected because of its tolerance to cold temperatures and its ability to persist on less fertile and low pH soils. Annual ryegrass was selected for its rapid germination to provide initial slope stability. The two other grasses, Pennlawn red

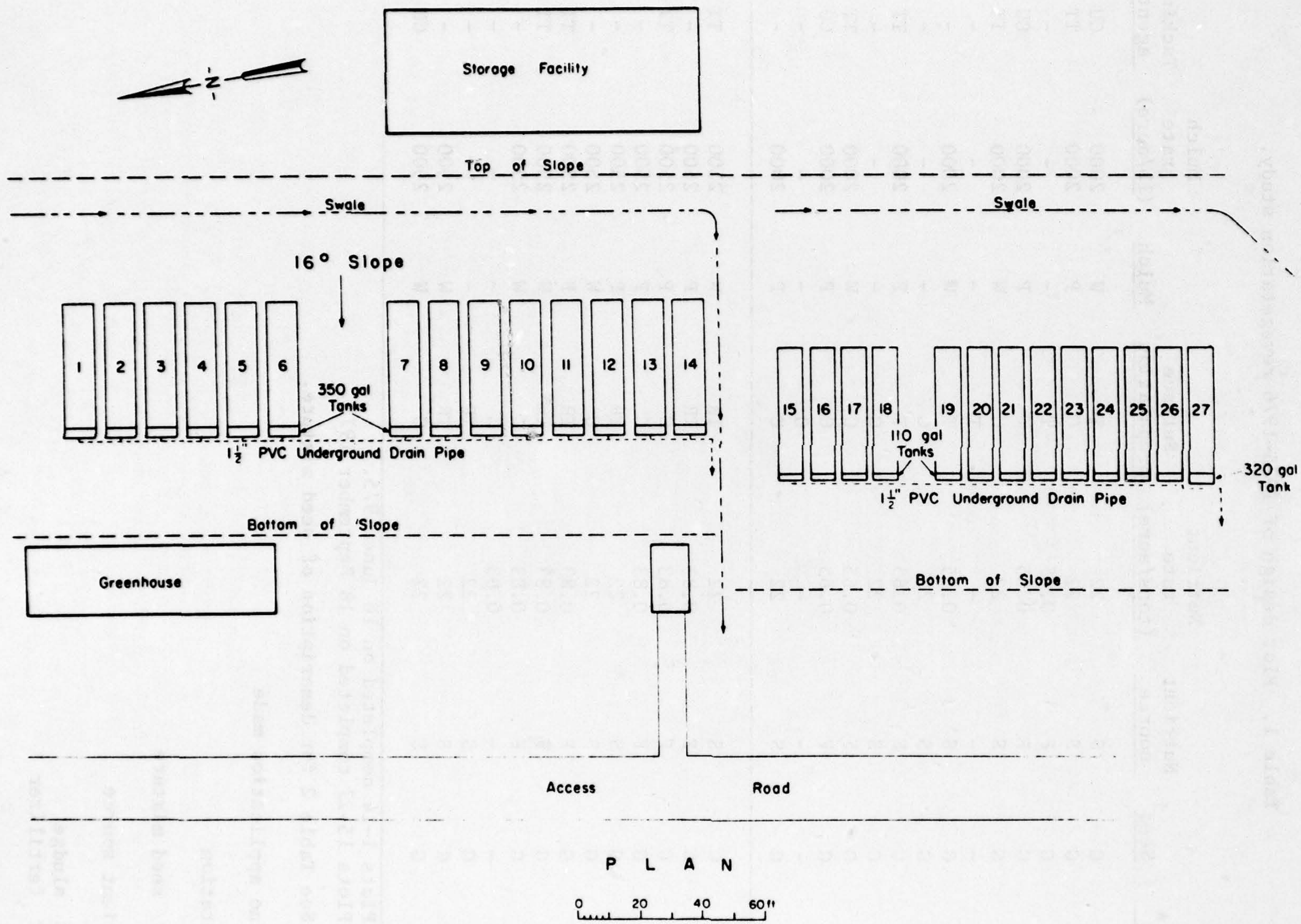

Figure 1. Plan of the 1975-76 stabilization study.

Table 1. Plot design of 1975-1976 revegetation study.

Plot*	Seed†	Nutrient source	Nutrient rate (tons/acre)	Surface preparation	Mulch	Mulch rate (lb/acre)	Tacking agent
1	G	S	22	T	W	2000	CU
2	G	S	22	C	P	2000	TT
3	G	F	0.65	T	-	-	-
4	G	F	0.65	T	P	2000	CU
5	G	S	22	C	W	2000	TT
6	-	-	-	T	-	-	-
7	G	S	0.65	T	W	2000	-
8	G	S	22	C	-	-	-
9	G	F	0.65	T	P	2000	TT
10	G	S	22	C	-	-	-
11	G	F	0.65	C	W	2000	TT
12	G	F	0.65	C	P	2000	CU
13	-	-	-	C	-	-	-
14	G	S	22	C	P	2000	-
15	G	S	22	TR	W	2500	TT
16	G	F	0.83	TR	P	2500	-
17	G	F	0.83	C	P	2500	TT
18	G	F	0.83	C	P	2500	-
19	G	S	22	TR	P	2500	-
20	G	S	22	C	W	2500	-
21	G	F	0.83	TR	P	2500	TT
22	G	F	0.83	TR	W	2500	TT
23	G	F	0.83	C	W	2500	-
24	-	-	0.83	C	-	-	-
25	G	S	22	TR	-	-	-
26	G	S	22	TR	W	2500	-
27	G	S	22	C	W	2500	CU

* Plots 1-14 completed on 16 June 1975.
Plots 15-27 completed on 18 September 1975.

† See Table 2 for description of seed mixture.

- no application made

Vegetation

G seed mixture

Nutrient source

S sludge
F fertilizer

Table 1 (cont'd).

Surface preparation

- T soil tilled to a depth of 4 in.
- C soil compacted with bulldozer blade
- TR soil tracked with cleats of bulldozer tracks

Mulches

- W wood fiber mulch
- P peat moss

Tacking agents

- TT Terra Tack III
- CU Curasol LP AE/1

Table 2. Seed mixture.

Seed type	Rate (lb/acre)
Pennlawn red fescue (*Festuca rubra* L.)	40
K-31 tall fescue (*Festuca arundinacea* Schreb.)	30
Annual ryegrass (*Lolium multiflorum* L.)	10
Birdsfoot trefoil (*Lotus coiniculatus* L.)	10
Total	90

10

fescue and K-31 tall fescue, are both perennials and tolerate wide ranges in soil pH and temperature. Red fescue is also tolerant of droughty soils.

Physical preparation of the soil surfaces included tilling, bulldozer tracking, and compaction (Table 1). After nutrient sources were applied, tilling was done to a depth of 4 in. Tracked surfaces were prepared by running a bulldozer up and down the slope, making small depressions from the track cleats. Compacted plots were made by back-dragging with the dozer blade after the sod had been removed.

The nutrient sources tested were 5-10-5 slow release fertilizer and sewage sludge (Table 1). The 5-10-5 grade fertilizer that was used consisted of the standard 5% nitrogen (N), 10% phosphorus pentoxide (P_2O_5) and 5% potassium oxide (K_2O). It was applied at 1308 lb/acre on plots 1-14 and 1656 lb/acre on plots 15-27. The sewage sludge used was a dewatered, anaerobically digested sludge obtained from the Hanover sewage treatment plant. It was applied at the rate of 22 tons/acre, which provided a good surface cover. The sludge was analyzed at the University of Wisconsin following the procedures of Liegel and Schulte (1977). It was near neutrality in pH and contained 1.22% N, 1.43% P_2O_5, and 2.98% K_2O on a wet weight basis. The moisture content of the sludge was 33%.

Wood fiber mulch and peat moss were applied as mulching agents for moisture retention. For comparison with the treated plots, some plots did not receive either mulching agent (Table 1). Wood fiber mulch was chosen for its relatively low cost and ease of shipment. Peat moss was tested because of its availability and potential for use in Alaska. Both mulches were applied according to the manufacturer's recommendations to the appropriate plots at 2000 lb/acre on plots 1-14 and at 2500 lb/acre on plots 15-27.

The two types of chemical tacking agents used with the mulches were Terra Tack III and Curasol LP AE/1 (Table 1). A tacking agent is a type of "glue" which forms a semiporous crust, locking seed, mulch and surficial soil particles together while still allowing moderate rainfall to soak through to the soil. Terra Tack III consists of a free-flowing granular powder produced from seaweed extracts. It was mixed with water to form a slurry with a pH of 7-8 and applied at a rate of 80 lb/acre. Curasol LP AE/1 is a white, milky liquid with a pH of 4-5. It was diluted at the rate of 50:1 and applied at a rate of 198 lb/acre. The tackifier rates were determined by field testing.

SITE CONSTRUCTION

The original construction of the 1975-76 demonstration site during June 1975 involved 1) removing the sediment collection tanks from the 1974-75 study, 2) scraping the sod off the slope surface, 3) removing the loose material left by the bulldozer, 4) installing collection tanks and underdrains for plots 1-27, and 5) grooming the slope (Fig. 2-7). This process is described in detail in a previous CRREL Technical Note (Hannel et al. 1976).

Fertilizer, sludge, and mulching material were applied first to the appropriate plots followed by application of the seed mixture (Fig. 8-10). Next, the chemical tacking agents were mixed in a hydromulcher (Fig. 11-13) and sprayed on the appropriate plots. All plots were completed on 16 June 1975.

Destruction

Twice during the summer, plots 15-27 were damaged. Heavy rainfall (2.28 in.) occurred on 13 July 1975, disrupting drainage from the CRREL south parking lot and causing extensive flooding at a construction area just east of this study site. The water flowed west and badly damaged plots 15-27 (Fig. 14 and 15). Due to proper drainage above them, plots 1-14 survived the storm. In late July, the damaged plots were reshaped and reseeded for temporary stabilization. Then on 4 August 1975, a water main broke just to the east of plots 15-27. Approximately 1.5 million gallons of water ran down the slope removing 160 yard^3 of soil (Fig. 16). In mid-August, the slope was again reshaped by the contractor responsible for the water line break.

On 18 September 1975, reinstallation of plots 15-27 was completed. The sediment collection tanks and underdrain system were replaced, and the surface treatments were reestablished (Fig. 17-19).

DATA ACQUISITION

Weather, vegetation, and soil loss data were collected from June 1975 to September 1976 to determine the effectiveness of the applied treatments.

Precipitation and air temperature were recorded hourly to determine if treatments were applied during a nearly normal climatic year.

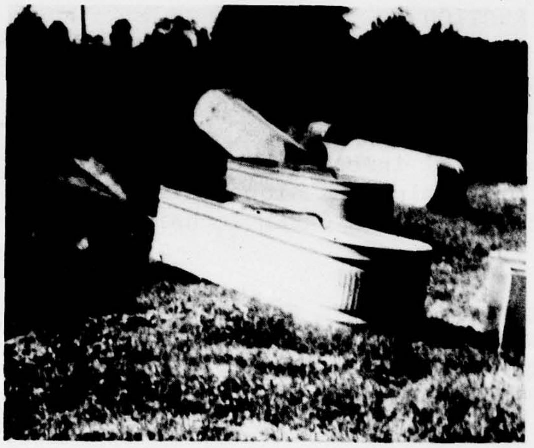

Figure 2. Removing the sedimentation tanks from the 1974-75 experiment.

Figure 3. Removing sod from the plots.

Figure 4. Placing the tanks in the trench.

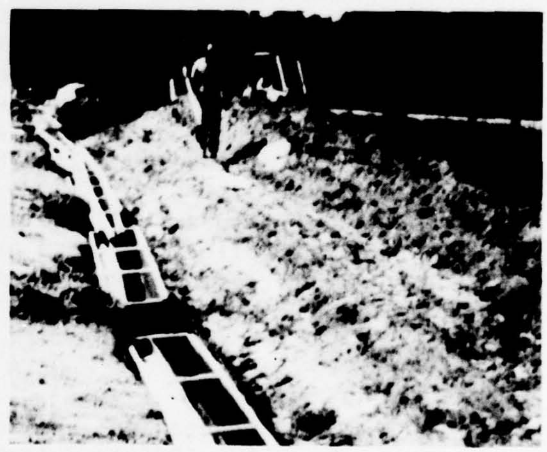

Figure 5. Preparing to install tanks 15-27.

Figure 6. Installing the under-drains for the tanks.

Figure 7. Placing soil around the tanks.

Figure 8. Spreading sludge on the plot.

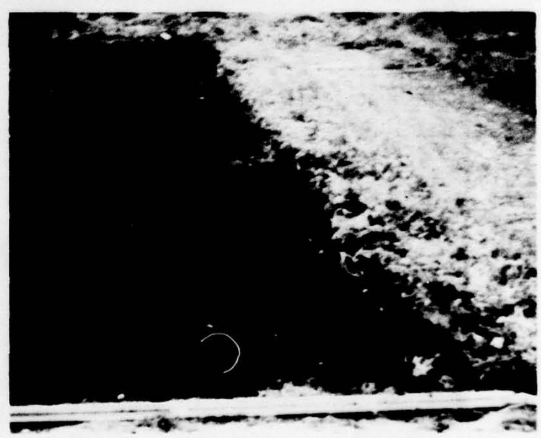

Figure 9. Completed plot with sludge.

Figure 10. Spreading peat moss on the plot.

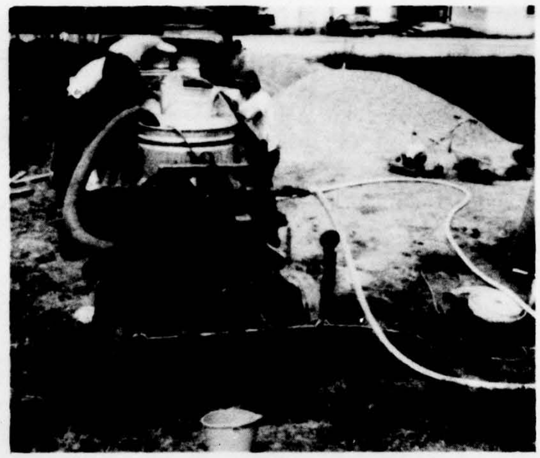

Figure 11. CRREL's homemade hydromulcher.

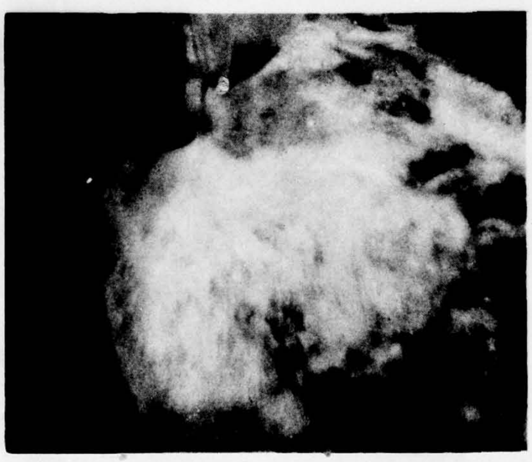

Figure 12. Mixing Terra Tack III in hydromulcher.

Figure 13. Mixing Curasol in hydromulcher.

Figure 14. Damage to plot looking downslope.

Figure 15. Closeup of damage showing extent of erosion.

Figure 16. Overall view of damage incurred by water main break, looking southeast.

Figure 17. Tracking of the soil on the test plots.

Figure 18. View of finished plots prior to the installation of the sediment tanks.

Figure 19. Replacing the sedimentation tanks with underdrains.

Vegetation was assessed by recording plant yields and botanical ratings of the various treatments. Plant yields are the weight of vegetation removed from each plot during harvests converted to lb/acre. These were determined twice in 1975 (15 August, 22 September) and twice in 1976 (23 June, 24 August) by cutting the plants at a 3-in. height with a sickle-bar mower. The removed vegetation was weighed to give fresh weight yields per plot. A hand-size grab sample of the vegetation from each plot was dried at 110°F for 48 hours to determine its water content. The water content data were then used to convert the total fresh weight readings for each plot to the equivalent dry weight. Botanical ratings were taken in 1975 on 26 September and in 1976 on 24 July and 6 October. These are visual estimates of the types and percentage of plant species present over the entire soil surface of each plot.

Sediment loss was determined by collecting and weighing the material that had washed into the collection tanks at the base of the plots. This was done in 1975 on 28 July and 17 September for plots 1-14 and on 23 September and 7-9 October for plots 15-27. In 1976, soil loss measurements were taken from all plots on 7 July. Again, a hand-size sample from each plot was dried at 110°F for 48 hours to determine the percentage of water content. Total weight data for each plot were then converted to the equivalent dry weights.

RESULTS

Climate and Meteorological Data

Precipitation and air temperature readings taken during the study are presented in Table 3 along with the 30-year long-term normal for 1941-1970 (U.S. Dept. of Commerce 1973). The data are arranged to coincide with the two test periods: 16 June 1975 to 28 September 1976 (plots 1-14) and 28 September 1975 to 28 September 1976 (plots 15-27). In general, the test periods were wet with essentially normal temperatures.

Precipitation for the period 16 June '75 to 28 September '76 (study plots 1-14) totaled 58.81 in., which is 7.68 in. above normal for the period. During the year 28 September '75 to 28 September '76 (study plots 15-27), precipitation was 46.37 in., 9.07 in. greater than the normal yearly precipitation. October 1975 had the greatest departure from normal when 5.60 in. of precipitation was recorded (double the normal amount for the month).

Maximum precipitation for one day, 2.28 in., was observed on 13 July 1975. It occurred with heavy thundershower activity when 1.02 in. of the total fell between 0600 and 0700 EST. This daily rainfall amount was the greatest recorded since measurements commenced at CRREL in October 1972 (U.S. Army Electronics Command 1972-1976). This excess water resulted in the first washout of plots 15-27, as stated earlier.

Table 3. Climatic summary at CRREL meteorological site, June 1975-September 1976.

Month	Temperature (°F) Normal	Temperature (°F) 1975 total at site	Precipitation (in.) Normal	Precipitation (in.) 1975 total at site	Max. precip. in 1 day
Jun	64.6	63(68.2)*	3.30	3.16(0.23)*	1.03 12th
Jul	69.2	71	4.18	4.60	2.28 13th
Aug	67.2	67	3.07	3.99	1.40 7th
Sep	59.4	56 (57)†	3.38	3.62(0.0)†	0.89 26th
Oct	48.3	49	2.82	5.60	1.83 18th
Nov	36.5	41	3.36	4.23	1.07 21st
Dec	22.9	19	2.72	2.60	1.06 26th
		1976		1976	
Jan	19.2	10	2.87	3.09	1.07 27th
Feb	20.9	26	2.40	3.42	1.00 2nd
Mar	30.5	32	2.77	1.79	0.56 27th
Apr	43.4	48	3.13	3.03	1.60 1st
May	55.3	53	3.30	5.64	1.42 19th
Jun	64.6	68	3.30	4.29	0.93 16th
Jul	69.2	66	4.18	5.12	1.49 11th
Aug	67.2	65	3.07	4.38	1.25 15th
Sep	59.4	55	3.38	3.18	1.00 26th

Mean annual temperature = 44.8°F. Mean annual precipitation = 37.3 in.

Plots 1-14 dates of testing, 16 June '75 - 28 September '76.
Plots 15-27 dates of testing, 28 September '75 - 28 September '76.

*15 days - average temperature and total precipitation for 15 days in June after the project started on 16 June 1975.

† 3 days - average temperature and total precipitation for the 3 days of September following reconstruction of plots 15-27.

Air temperature was near normal for both test periods (Table 3). The largest departure from normal occurred in January 1976 when the mean air temperature was 9.2°F below normal.

Vegetation Yields

Results of the four vegetation harvests (plant yields) for the individual plots are listed in Table 4. Yields from all the plots with the same treatment variable were averaged to note any response to the variables of nutrient source, mulch and surface preparation (Table 5). This grouping method involves considering one variable at a time, although the two other variables are indirectly included in the data.

Nutrient applications - sewage sludge and fertilizer

The nutrient applications of fertilizer or sewage sluge were included to compare the effects of these materials on plant yields and on the presence of individual species for each treatment.

Table 5a and Figure 20 show the differences in average plant yield produced by all the sludge- and fertilizer-treated plots. Grasses and legumes seeded in spring initially produced higher yields in treatments which received fertilizer. After the first cutting (15 August 1975), treatments which received sludge were the greater yielders. In the fall-seeded plots, greater yields were obtained from those plots receiving sewage sludge.

In both the spring and fall seedings, differences in yields between the two fertility sources can be related to the release of plant-available nutrients from the sewage sludge. Of the plant nutrients, nitrogen is the element that most stimulates plant growth. Most of the nitrogen

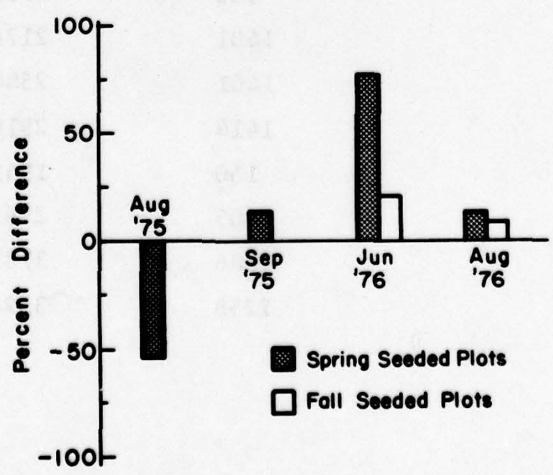

Figure 20. Percentage difference in vegetation yields produced by plots treated with sludge relative to fertilizer treated plots.

Table 4. Vegetation yields obtained during harvests (lb/acre dry weight).

Plot	15 Aug 1975	22 Sep 1975	23 Jun 1976	24 Aug 1976	Total
	Vegetation Yields (lb/acre)				
1	1046	327	1995	2333	5701
2	730	164	1352	1831	4077
3	2453	153	458	1308	4372
4	2987	87	676	1733	5482
5	414	174	818	2082	3488
6	0	55	240	730	1025
7	1700	109	1591	2256	5656
8	447	218	1275	2169	4109
9	567	436	1046	2104	4153
10	1014	76	87	316	1493
11	1101	109	294	1199	2703
12	1003	109	174	785	2071
13	0	98	164	512	774
14	916	185	2017	2027	5145
15			911	1999	2910
16			979	1958	2937
17			762	2761	3523
18			1251	2244	3495
19			1238	2026	3264
20			966	1782	2748
21			1401	2176	3577
22			1401	2584	3985
23			1414	2910	4324
24			150	1945	2095
25			1605	2965	4570
26			1686	3781	5467
27			2258	3522	5780

Table 5. Influence of treatment variables on average vegetation yields (lb/acre dry weight).

	Vegetation yields (lb/acre)*				
	1975		1976		Total
	Aug	Sep	Jun	Aug	
a. *Nutrient source*					
Spring seeding					
Sludge	761	191	1257	1793	4002
Fertilizer	1635	167	707	1564	4073
Fall seeding					
Sludge	--	--	1444	2679	4123
Fertilizer	--	--	1201	2439	3640
b. *Mulch*					
Spring seeding					
WFM	1065	180	1175	1968	4388
PM	1241	196	1053	1696	4186
None	1305	149	607	1264	3225
Fall seeding					
WFM	--	--	1439	2763	4202
PM	--	--	1126	2233	3359
None	--	--	1605	2965	4570
c. *Surface preparation*					
Spring seeding					
Tilled	1751	222	1153	1947	5073
Compacted	804	148	860	1487	3299
Fall seeding					
Tracked	--	--	1317	2498	3815
Compacted	--	--	1330	2644	3974
d. *Controls*					
Spring seeding	0	77	202	621	900
Fall seeding	--	--	150	1945	2095

* Yield data are averages of all the plots that received the variable listed.

contained in sludge is in organic form. Warm soil temperatures and adequate soil moisture are needed to transform elements, particularly nitrogen, to a form available to plants. Therefore, spring seedings (in cool soils) require longer periods of time to break down sludge than do late summer-fall seedings (in warm soils).

In the case of the fertilizer used in this study, 70% of the nitrogen applied should be readily available to plants and not affected by soil temperatures. This accounts for the good initial response of spring-seeded plots treated with fertilizer.

Another point to consider is that much of the nutrients applied through fertilizers in the fall could have been lost in the soil through the winter and not available to plants for the following spring growth. In this case the fertilizer treated plots would become less efficient, resulting in the similar yields noted for both sludge and fertilizer treated plots from the fall seeding time.

From the data it appears that anaerobically digested sewage sludges, when available, can be substituted for commercial fertilizers as fertility sources when seeding in fall. For spring seedings, sludges may also be substituted in areas that are not highly erodible. In highly erodible soils, fertilizers should be used alone or in combination with sludge.

Mulch applications - wood fiber mulch or peat moss.

Greater variability in yields between the mulched and unmulched treatments occurred for the spring-seeded as compared to the fall-seeded plots (Table 5 and Fig. 21). No great difference in yields was noted between wood fiber mulch and peat moss.

The greatest differences between the mulched plot yields and the unmulched (i.e. control) plot yields in the spring seeding were noted the second season. The reason for this later effect is not clear. One possibility could be that the vegetation did not become fully established during the first growing season and that the retention of moisture by the mulches during the next season was important with regard to plant growth. In the fall-seeded plots, the control (no mulch) and wood fiber mulch treatments produced the higher yields.

Surface preparation - tilled, compacted or tracked.

Various soil cultivation techniques were also studied. Soil preparation by compaction was compared to tillage in the spring seeding and to tracked soil in the fall seeding.

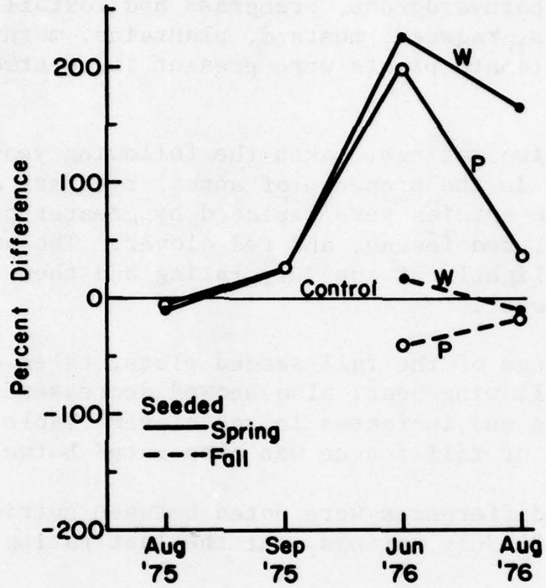

Figure 21. Percent difference in vegetation yields produced by mulched plots vs unmulched plots (w-wood fiber mulch, p-peat moss).

Table 5c compares the average yields produced by the various surface preparation techniques. It shows that surface preparation does affect the quantity of plant production. For the spring seeded plots, those with a tilled surface produced greater yields than the compacted plots (5073 lb/acre vs 3299 lb/acre, total). Among fall-seeded plots, the compacted surfaces produced yields somewhat greater than the tracked surfaces (3974 lb/acre vs 3815 lb/acre).

Botanical Ratings

Table 6 lists the average botanical ratings for sludge- and fertilizer-treated plots. These data can be used to note the establishment and persistence of the cover crop (annual ryegrass) after seeding and the emergence with time of the perennial species. The establishment and change in the vegetation at the site were noted for each nutrient.

The 26 September rating in the spring-seeded treatment shows the types and percentages of plants existing on the slope prior to the first

winter. At the first rating, high percentages of tall fescue, annual ryegrass, and other weedy species were noted. The weedy species consisted mostly of barnyardgrass, crabgrass and foxtail with smaller amounts of clovers, ragweed, mustard, plantains, morning-glory, smartweed and tomato. The tomato plants were present in treatments that received sewage sludge.

At the next two ratings, taken the following year on 24 July and 6 October, declines in the presence of annual ryegrass and weedy species were noted. These species were replaced by greater percentages of birdsfoot trefoil, red fescue, and red clover. The amount of tall fescue declined slightly at the July rating and then increased again for the rating in October.

The two ratings of the fall seeded plots, taken on 24 July and 6 October of the following year, also showed decreases in the percentage of annual ryegrass and increases in red clover (Table 6). An increase in the percentage of tall fescue was also noted between the two ratings.

Only slight differences were noted between nutrient sources for the 26 September and 24 July ratings. At the last rating (6 October)

Table 6. Average botanical ratings of sludge and fertilizer treated plots.

	Rating (% cover)					
Plant Species	26 September 75		24 July 76		6 October 76	
	S*	F*	S	F	S	F
Spring seeded:						
Tall fescue	28.3	30.8	20.8	13.3	40.8	25.8
Birdsfoot trefoil	10.0	8.3	26.7	28.3	20.8	26.7
Red fescue	6.7	5.0	15.0	21.7	20.8	30.0
Annual ryegrass	31.7	30.8	18.3	8.3	0.0	0.0
Red clover	0.0	0.0	12.5	15.0	17.5	16.6
Weeds	23.3	25.1	6.7	13.4	0.1	0.9
Fall seeded:						
Tall fescue	--	--	19.2	16.7	44.2	34.2
Birdsfoot trefoil	--	--	15.8	30.8	10.8	20.8
Red fescue	--	--	41.7	32.5	33.3	24.2
Annual ryegrass	--	--	23.3	21.7	0.0	0.0
Red clover	--	--	0.0	0.0	11.7	19.2
Weeds	--	--	0.0	0.0	0.0	1.6

*S = sewage sludge,
F = fertilizer.

higher concentrations of tall fescue were noted in the sludge treatments, while birdsfoot trefoil and red fescue were greater in the fertilized soils. The effect was noted at both seeding times.

The decline in the percentage of annual ryegrass and other weedy species, which consisted mainly of annuals, was likely due to their difficulty in reseeding themselves the following spring (1976) and to their intolerance of mowing when harvests were taken. In general, weedy species do not stabilize soils as well and are competitive to the growth of the perennial species.

The lower ratings recorded for tall fescue in July may be related to winterkill from the previous winter. Tall fescue is not tolerant of extremely cold temperatures. Although the percentage of tall fescue declined, the other perennial grasses sown were able to increase their presence. Therefore mixtures of grasses are more advantagous than those seeded alone for fighting invasions of insects and diseases which can kill certain grass types but not others.

Birdsfoot trefoil is a notably slow starter, as shown in Table 6, but during the following season this species was well established. Red fescue, like birdsfoot trefoil, began slowly in the spring seeding and then was more predominant the following season.

Red clover the dominant species on this slope prior to site construction, migrated into both the spring-seeded and fall-seeded areas during the second season.

The ratings of all perennial plants (plants which will permanently stabilize the soils) were averaged and compared to annual ryegrass (nurse crop) and weed species to note the transition of the two categories of plants at the site. Figure 22 shows that the transition between the two went smoothly. As the annual grasses died out, the perennial grasses became more prominent.

Soil Loss

Soil loss measurements taken twice in 1975 and once in 1976 are recorded in Table 7. The total soil loss from 1975 plus 1976 was used to rank the treatments in order of increasing soil loss, as given in Table 8. Also listed is the effectiveness percentage of each treatment. Effectiveness is defined as the amount of soil retained (not eroded) as compared to the control, and is calculated by the following equation:

$$\text{effectiveness (\%)} = 100 \left(\frac{\text{control plot soil loss - treated plot soil loss}}{\text{control plot soil loss}}\right)$$

Table 7. Soil loss yields (ton/acre dry weight).

Plot	1975				1976		Total
Date	28 July	17 Sept	23 Sept	7-9 Oct	7 July	5 Oct	'75 & '76
1	4.867	0.021			0.165		5.053
2	2.492	0.006			0.087		2.585
3	0.097	0.003			0.248		0.348
4	0.725	0.010			0.194		0.929
5	1.080	--			0.213		1.293
6	3.304	0.107		0.016	13.11		16.54
7	0.375	--			--		0.375
8	0.610	--			0.193		0.803
9	0.133	0.007			0.263		0.403
10	0.687	0.002			0.119		0.808
11	0.440	0.014			0.432		0.886
12	3.021	0.007			0.347		3.375
13	10.43	0.223		0.466	8.335		19.45
14	1.222	0.083			5.575		6.880
15			0.038	0.138	4.059		4.235
16			0.039	0.494	2.931		3.464
17			0.031	0.343	0.336		0.710
18			0.037	4.415	2.916		7.368
19			0.036	0.041	2.180		2.257
20			0.037	0.018	1.416		1.471
21			0.036	0.217	1.085		1.338
22			0.032	0.049	1.101		1.182
23			0.028	0.048	0.991		1.067
24			0.030	1.517	--	37.12	38.67
25			0.028	0.074	0.675		0.777
26			0.034	0.009	--		0.043
27			0.045	0.019	0.298		0.362

Table 8. Plots ranked in order of increasing soil loss.*

Rank	Plot	Soil loss tons/acre	Jun (J) vs Sep (S)	Effectiveness (%)	Surface preparation	Nutrient	Mulch	Tack	Vegetation production (lb/acre)	Veg. rank
1	26	0.043	S	99.83	TR	S	W	--	5467	5
2	3	0.348	J	98.60	T	F	-	--	4372	8
3	27	0.362	S	98.55	C	S	W	Cu	5780	1
4	7	0.375	J	98.49	T	F	W	--	5482	3
5	9	0.403	J	98.38	T	F	P	TT	4153	10
6	17	0.710	S	97.15	C	F	P	TT	3523	15
7	25	0.777	S	96.88	TR	S	-	--	4570	7
8	8	0.803	J	96.77	C	S	-	--	4109	11
9	10	0.808	J	96.75	C	S	-	--	1493	25
10	11	0.886	J	96.44	C	F	W	TT	2703	22
11	4	0.929	J	96.27	T	F	P	Cu	5482	4
12	23	1.067	S	95.71	C	F	W	--	4324	9
13	22	1.182	S	95.25	TR	F	W	TT	3985	13
14	5	1.293	J	94.80	C	S	W	TT	3488	17
15	21	1.338	S	94.62	TR	F	P	TT	3577	14
16	20	1.471	S	94.09	C	S	W	--	2748	21
17	19	2.257	S	90.93	TR	S	P	--	3264	18
18	2	2.585	J	89.61	C	S	P	TT	4077	12
19	12	3.375	J	86.44	C	F	P	Cu	2071	24
20	16	3.464	S	86.08	TR	F	P	--	2937	19
21	15	4.235	S	82.98	TR	S	W	TT	2910	20
22	1	5.053	J	79.70	T	S	W	Cu	5701	2
23	14	6.880	J	72.36	C	S	P	--	5145	6
24	18	7.368	S	70.39	C	F	P	--	3495	16
25	6	16.54	J	0	T	-	-	--	1025	26
26	13	19.45	J	0	C	-	-	--	774	27
27	24	38.67	S	0	C	-	-	--	2095	23

*For abbreviations see Table 1.

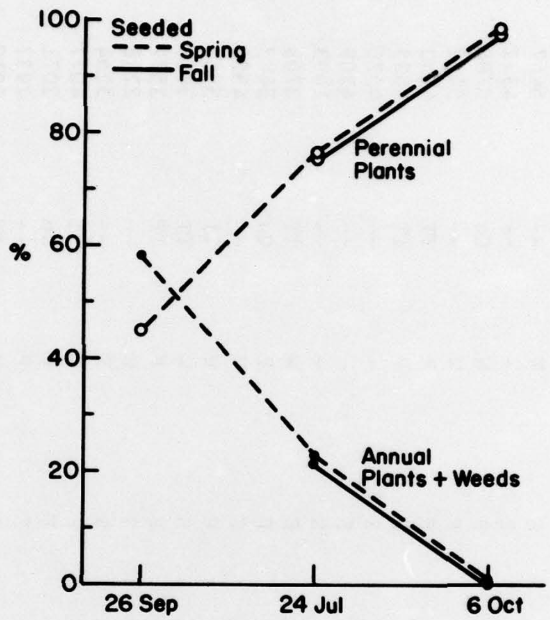

Figure 22. Percentages of annual and perennial plants growing at the site.

The control plot soil loss used for the calculations was 24.9 tons/acre, the average value from the three control plots (6, 13, and 24). Table 8 also includes the treatment variables and the month that the plot was seeded (June or September) so that the effect of all influences on soil loss can be evaluated.

No discernible trend was found to separate the plots completed in June from those completed in September. Therefore, both spring- and fall-seeded plots were considered together when comparing other treatment variables.

The plots were first examined for the influence of initial physical surface preparation. This analysis in Tables 9a through 9c gives soil loss data from tracked, compacted, and tilled surface preparations in tons per acre. It shows that all three surface preparations reduced erosion well, with an average effectiveness range of 91 to 94% compared to the controls. Within that narrow range, the tilled surface treatment was the most effective at 94.3%, with an average soil loss of 1.42 tons/acre. The tracked surface treatment was slightly less effective (92.4%), with a soil loss of 1.90 tons/acre, and the compacted surface treatment was least effective (90.8%) with a soil loss of 2.30 tons/acre.

Table 9. Influence of surface preparation on soil loss.

a. *Tracked surface*

Plot	Soil loss (tons/acre)	Effective-ness(%)	Nutrient source	Mulch	Tack	Vegetation production (lb/acre)	Veg. rank
26	0.043	99.83	S	W	-	5467	5
25	0.777	96.88	S	-	-	4570	7
22	1.182	95.25	F	W	TT	3985	13
21	1.338	94.62	F	P	TT	3577	14
19	2.257	90.93	S	P	-	3264	18
16	3.464	86.08	F	P	-	2937	19
15	4.235	82.98	S	W	TT	2910	20
Avg.	1.899	92.37				3816	14

b. *Compacted surface*

Plot	Soil loss (tons/acre)	Effective-ness(%)	Nutrient source	Mulch	Tack	Vegetation production (lb/acre)	Veg. rank
27	0.362	98.55	S	W	C	5780	1
17	0.710	97.15	F	P	TT	3523	15
8	0.803	96.77	S	-	-	4109	11
10	0.808	96.75	S	-	-	1493	25
11	0.886	96.44	F	W	TT	2703	22
23	1.067	95.71	F	W	-	4325	9
5	1.293	94.80	S	W	TT	3488	17
20	1.471	94.09	S	W	-	2747	21
2	2.585	89.61	S	P	TT	4077	12
12	3.375	86.44	F	P	C	2071	24
14	6.880	72.36	S	P	-	5145	6
18	7.368	70.39	F	P	-	3495	16
Avg.	2.301	90.76				3580	15

c. *Tilled surface*

Plot	Soil loss (tons/acre)	Effective-ness(%)	Nutrient source	Mulch	Tack	Vegetation production (lb/acre)	Veg. rank
3	0.348	98.60	F	-	-	4372	8
7	0.375	98.49	F	W	-	5656	3
9	0.403	98.38	F	P	TT	4153	10
4	0.929	96.27	F	P	C	5483	4
1	5.053	79.70	S	W	C	5701	2
Avg.	1.422	94.29				5073	5

Table 10. Influence of nutrient source on soil loss.

a. *Sewage sludge*

Plot	Soil loss (tons/acre)	Effective-ness(%)	Nutrient source	Mulch	Tack	Vegetation production (lb/acre)	Veg. rank
26	0.043	99.83	TR	W	-	5467	5
27	0.362	98.55	C	W	C	5780	1
25	0.777	96.88	TR	-	-	4570	7
8	0.803	96.77	C	-	-	4109	11
10	0.808	96.75	C	-	-	1493	25
5	1.293	94.80	C	W	TT	3488	17
20	1.471	94.09	C	W	-	2747	21
19	2.257	90.93	TR	P	-	3264	18
2	2.585	89.61	C	P	TT	4077	12
15	4.235	82.98	TR	P	TT	2910	20
1	5.053	79.70	T	W	C	5701	2
14	6.880	72.36	C	P	-	5145	6
Avg.	2.214	91.10				4063	12
			b. *Fertilizer*				
3	0.348	98.60	T	-	-	4372	8
7	0.375	98.49	T	W	-	5656	3
9	0.403	98.38	T	P	TT	4153	10
17	0.710	97.15	C	P	TT	3523	15
11	0.886	96.44	C	W	TT	2703	22
4	0.929	96.27	T	P	C	5483	4
23	1.067	95.71	C	W	-	4325	9
22	1.182	95.25	TR	W	TT	3985	13
21	1.338	94.62	TR	P	TT	3577	14
12	3.375	86.44	C	P	C	2071	24
16	3.464	86.08	TR	P	-	2937	19
18	7.368	70.39	C	P	-	3495	16
Avg.	1.787	92.82				3857	13

Next the plots were examined for the influence of the applied nutrient source. Twelve plots were treated with sludge and 12 with fertilizer. These are shown in Tables 10a and 10b, ranked in order of increasing soil loss. Both sludge and fertilizer were similarly effective against erosion. Average soil loss from the fertilizer-treated plots was 1.79 tons/acre (92.8% effective), while the loss from the sludge treated plots was 2.21 tons/acre (91.1%).

Finally, the plots were grouped according to mulch plus tacking agent and again arranged in order of increasing soil loss (Table 11). Table 11 shows that 1) the no mulch-no tacking agents plots had low soil loss with an average of 0.69 tons/acre (97.3% effective), 2) wood fiber mulch-no tacking agent plots also had very little soil loss with 0.74 tons/acre (97.0%), and 3) Terra Tack III treated plots were next (avg. effectiveness 93.7%) followed by Curasol treated plots (avg. 90.3%) and finally plots with peat moss and no tacking agent (79.9%).

Table 11. Influence of mulch and tacking agent on soil loss.

Mulch	Tack	No. of plots	Avg. soil loss (tons/acre)	Effectiveness (%)	Avg. veg. prod. (lb/acre)	Veg. prod. rank
-	-	4	0.69	97.25	3636	6
W	-	4	0.74	97.03	4549	2
P	TT	4	1.26	94.94	3833	3
W	TT	4	1.90	92.37	3272	7
P	C	2	2.15	91.36	3777	4
W	C	2	2.71	89.13	5741	1
P	-	4	4.99	79.94	3710	5

COST ANALYSIS

The cost of each treatment was computed by totaling the cost of materials and installation expenses. The costs were taken from national averages given in Building Construction Cost Data (Robert Snow Means Co. 1978), a reference to aid contractors in anticipating their construction expenses. Table 12 separately lists these materials and installation costs on a per acre basis along with a reference to the line in Cost Data that was the source of the figures. Bare costs are given separately from the final total, which includes a profit of 10% above the bare materials cost and an overhead and profit of 40% above the bare installation cost.

Table 12. Costs used in analysis ($/acre).

Material	Abbr.	BARE COST ($/acre) Mat†	Inst†	Total w/O&P	Cost Data line reference			Crew	Daily output
Fertilizer	F	495		545	2.8	45	100		
Grass seed	G	376		415	2.8	45	100		
Mulches	M								
Wood fiber mulch	W	242		265	2.8	45	110		
Peat moss	P	242		265	2.8	45	110		
Tackifier									
Terra Tack 3	TT3	260		285	**				
Curasol	Cu	89		100	**				
Installation									
Hydromulching (w/F and G) -			581	815	2.8	45	100		
" (w/F,G and M)			581	815	2.8	45	110		
Sludge (22 T/A)	S								
Hauling and Stockpiling			34	50	*				
Spreading			532	745	2.8	25	10	B-10B	1.61
			566	795					
Surface preparations	SP								
Tracking	TR		1161	1625	2.3	22	210	B-11L	0.33
Tilling	T		1161	1625	2.3	22	210	B-11L	0.33
Compacting	C		1161	1625	2.3	22	210	B-11L	0.33

* Value found in Cost Data not considered reasonable -- figure is estimated.
** No equivalent found in Cost Data - figures are based on actual cost.
† Mat -- materials cost; Inst -- installation cost; w/O&P -- with overhead and profit.

Table 12 also references the crews used for the estimation of installation costs and their daily output. Further breakdown of crew costs are shown in Table 13 on an hourly and daily basis. The crew cost for hydromulching is missing because it was not given in Cost Data.

Several generalizations were made to simplify the cost analysis. Installation costs for grass, fertilizer, mulch, and tacking agents were computed as if they had been applied by hydromulcher. Material costs for grass, fertilizer and both mulches were constant regardless of the rate applied. These were based on the national average for hydraulic seeding and mulching listed in Cost Data (Table 12). Tackifier costs, not listed in Cost Data, were based on actual cost to CRREL.

Sludge application and surface preparations involved installation costs only. Sludge application cost was considered equivalent to stockpiling and spreading of topsoil. Since the stockpiling cost given in Cost Data seemed unreasonably low, a delivery charge of $34 per 22-ton truckload was substituted. Surface preparations -- compacting, tilling, and tracking -- were all considered equivalent to the finish grading process given in Cost Data.

Table 14 shows the cost breakdown of all the treatments in order of increasing total cost. Cost breakdown for each treatment consists of one to three lines. The first line gives the hydromulching cost. Surface preparation cost is second and sludge application cost is third, when present. These are followed by the total of the above costs. As in Table 12, bare costs are listed separately from the total with overhead and profit.

Treatments with costs modified from the line exactly as it appears in Cost Data have an "M" added to the end of the line reference in Table 14. Modifications consisted of: 1) the addition to or subtraction from the materials cost in the hydromulching procedure, and 2) the addition of the hauling cost to the sludge installation cost.

The range in total cost (with overhead and profit) is from $1625/acre for the controls to $4195/acre for the treatment with sludge, mulch, and Terra Tack III (Tables 14 and 15). Within this range, treatments become more expensive as other factors are added to the basic surface preparation cost (Table 15). When all other factors are constant, sewage sludge is a more expensive nutrient source than fertilizer.

To aid comparison of a treatment's cost with its effectiveness in reducing erosion, Table 15 lists the cost of each treatment along with soil loss and vegetation yields. Figure 23 also shows the relation of cost to soil loss. The most cost-effective treatment (plot 3) appears to be that with fertilizer alone. It is the least expensive ($3395/acre), excluding the controls, and has a soil loss of only 0.35 tons/acre (98.6% effective). The treatment with sewage sludge alone (plots 8, 10 and 25) runs second with a cost of $3645/acre and an average soil loss of 0.8 tons/acre (96.8% effective).

Table 13. Crew and equipment costs.

Crew		Bare Cost Hr	Bare Cost Daily	Incl. subs O&P* Hr	Incl. subs O&P* Daily
B-10B					
1	equipment operator	$12.60	$100.80	$17.95	$143.60
0.5	building laborer	9.70	38.80	13.50	54.00
1	dozer, 180 HP		272.80		300.10
			$322.40		$507.70
B-11L					
1	equipment operator	$12.60	$100.80	$17.95	$143.60
1	building laborer	9.70	77.60	13.50	108.00
1	self-propelled grader		203.80		223.70
			$381.80		$475.30

*Incl. Subs O&P - including subcontractors' overhead and profit.

Table 14. Treatment cost breakdown.

Plot nos.	Treatment*	Cost Data line reference			BARE COST ($/acre) Mat	Inst.	Total	Total W/O&P
75-6,13,24	SP	2.3	22	210	-	1161	1161	1625
75-3	G F	2.8	45	100	871	581	1452	1770
	SP	2.3	22	210	-	1161	1161	1625
					871	1742	2613	3395
75-8,10,25	G	2.8	45	100M†	376	581	957	1225
	SP	2.8	22	210	-	1161	1161	1625
	S	2.8	25	10M	-	566	566	795
					376	2308	2684	3645
75-7,16, 18,23	G F M	2.8	45	110	1113	581	1694	2035
	SP	2.3	22	210	-	1161	1161	1625
					1113	1742	2855	3600
75-4,12	G F M Cu	2.8	45	110M	1202	581	1783	2135
	SP	2.3	22	210	-	1161	1161	1625
					1202	1742	2944	3760
75-14,19, 20,26	G M	2.8	45	110M	618	581	1199	1490
	SP	2.3	22	210	-	1161	1161	1625
	S	2.8	25	10M		566	566	795
					618	2308	2926	3910
75-9,11,17 21,22	G F M TT	2.8	45	110M	1373	581	1954	2325
	SP	2.3	22	210	-	1161	1161	1625
					1373	1742	3115	3950
75-1,27	G M Cu	2.8	45	110M	707	581	1288	1590
	SP	2.3	22	210	-	1161	1161	1625
	S	2.8	25	10M	-	566	566	795
					707	2308	3015	4010
75-2,5,15	G M TT	2.8	45	110M	878	581	1459	1780
	SP	2.3	22	210	-	1161	1161	1625
	S	2.8	25	10M	-	566	566	790
					878	2308	3186	4195

* See Table 12 for abbreviations.
† Modified from exact listing in Cost Data (see text)

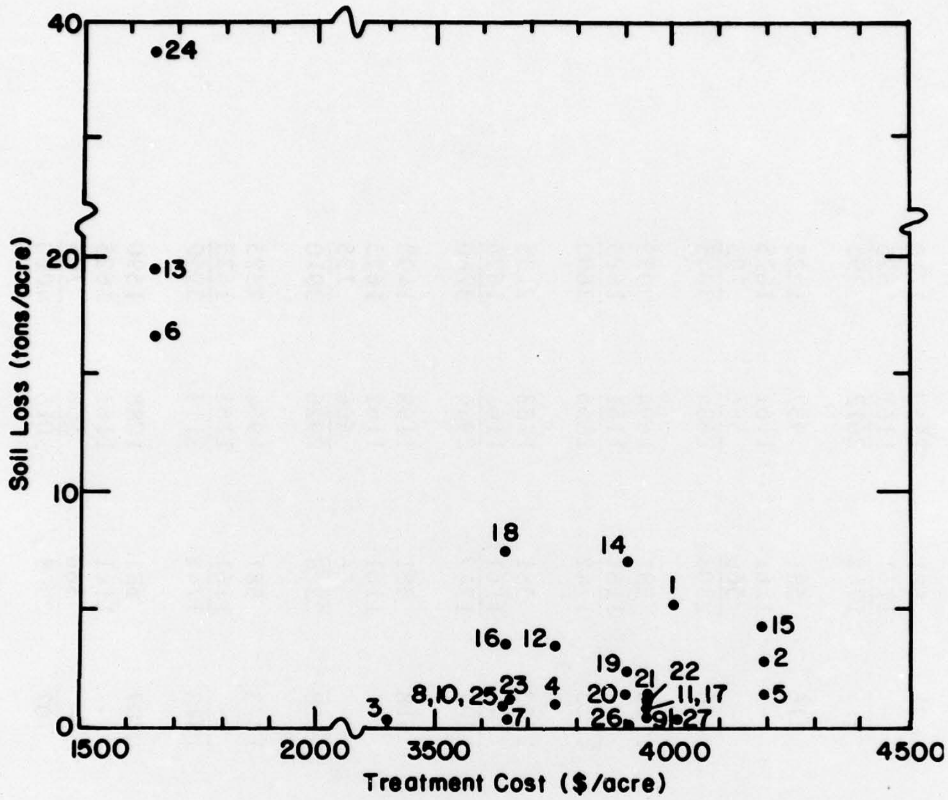

Figure 23. Treatment cost vs resulting soil loss. Figures adjacent to circles indicate plot number.

Table 15. Treatment cost vs effectiveness.

Rank	Plot no.	Treatment* SP	Nutrient	Mulch	Tack	Yields Soil loss (tons/acre)	Grass (lb/acre)	Effectiveness (%)	Cost Total w/O&P ($/acre)
1	24	T	-	-	-	38.67	2095	0	1625
2	13	C	-	-	-	19.45	774	0	"
3	6	C	-	-	-	16.45	1025	0	"
4	3	T	F	-	-	0.348	4372	98.60	3395
5	25	TR	S	-	-	0.774	4570	96.88	3645
6	10	C	S	-	-	0.808	1493	96.75	"
7	8	C	S	-	-	0.803	4109	96.77	"
8	7	T	F	W	-	0.375	5656	98.47	3660
9	23	C	F	W	-	1.067	4324	95.71	"
10	16	TR	F	P	-	3.464	2937	86.08	"
11	18	C	F	P	-	7.368	3495	70.39	"
12	4	T	F	P	C	0.929	5482	96.27	3760
13	12	C	F	P	C	3.375	2071	86.44	"
14	26	TR	S	W	-	0.043	5467	99.83	3910
15	20	C	S	W	-	1.471	2748	94.07	"
16	19	TR	S	P	-	2.257	3264	90.93	"
17	14	C	S	P	-	6.880	5145	72.36	"
18	9	T	F	P	TT	0.403	4153	98.38	3950
19	17	C	F	P	TT	0.710	3522	97.15	"
20	11	C	F	W	TT	0.886	2703	96.44	"
21	22	TR	F	W	TT	1.182	3985	95.25	"
22	21	TR	F	P	TT	1.338	3577	94.62	"
23	27	C	S	W	C	0.360	5780	98.55	4010
24	1	T	S	W	C	5.053	5701	79.70	"
25	5	C	S	W	TT	1.293	3488	94.80	4195
26	2	C	S	P	TT	2.585	4077	89.61	"
27	15	TR	S	W	TT	4.235	2910	82.98	"

* abbreviations - see Table 12

SUMMARY AND CONCLUSIONS

During the two-year (June 1975 to September 1976) stabilization research/ demonstration study at CRREL in Hanover, New Hampshire, several treatment types were studied to determine their effectiveness in controlling erosion on a 16° slope. Climatic conditions throughout the duration of the study included precipitation amounts 7.68 in. higher than normal and average temperatures. Maximum daily precipitation occurred on 13 July 1975 when 2.28 in. of rain fell, causing flooding and destruction of half the study plots. Since plots (15-27) were reestablished in September, the study includes both spring and fall seeded plots.

Initial surface preparation, nutrient source, mulching agent, and tacking compounds were the treatment variables studied along with a constant seed mix. The relative value of each treatment was determined through vegetation and soil loss yields.

All three surface preparations were quite effective in controlling erosion. Tilled soils produced the highest vegetation yields (5073 lb/acre) and had low soil loss (1.42 tons/acre; 94.3% effective compared to control). Tracked soils produced 3816 lb/acre of vegetation and had 1.90 tons/acre soil loss (92.4% effective). Compacted soils were slightly less effective with 3580 lb/acre vegetation and 2.30 tons/acre soil loss (90.8% effective).

It is difficult to separate fertilizer from sewage sludge as to which is the most effective nutrient source. They both had low average soil loss; fertilizer-treated plots had 1.79 tons/acre soil loss (92.8% effective) and sludge-treated plots had 2.21 tons/acre (91.1%). Vegetation yields from the spring-seeded plots were initially higher on the fertilizer-treated plots, but after the first cutting, yields were higher on the sludge-treated plots. Yields from the fall-seeded plots were consistently higher on the sludge-treated plots.

Mulch and tack application effects were considered together. Vegetation yields indicated minor differences between mulch treatments or between mulched and non-mulched plots. Soil loss results, however, indicate that the no mulch-no tacking agent treatment and the wood fiber mulch-no tacking agent treatment were the most effective (97%). The use of peat moss as a mulch or either of the tacking agents (Terra Tack III or Curasol) increased the amount of soil loss slightly.

The seed mixture studied provided good results regarding persistence on the slope. The nurse crop, annual ryegrass, was the dominant species during the initial season. Thereafter, the perennial species dominated

the site. Birdsfoot trefoil, red clover, red fescue, and tall fescue were species that appeared to perform well in this type of environment.

A cost analysis of the individual treatments was also prepared. The treatments ranged in expense from $1625/acre to $4195/acre. The more expensive treatments were those with more variables included. The least expensive were combinations with sludge, wood fiber mulch, or Curasol. The most cost-effective treatment had fertilizer as a nutrient source with no mulch or tacking agent. This treatment had a soil loss of only 0.4 tons/acre (98.6% effectiveness compared to average control) and was the least expensive treatment (other than the controls) at only $3395/acre. The treatment with sludge alone was a close second with a cost of $3645/acre and an average soil loss of 0.8 tons/acre.

Based on the foregoing cost analysis and soil loss data, a recommended treatment would include a surface prepartion, fertilizer or sludge application, and seeding with a seed mixture. Additional mulch and tackifiers add to the cost but do not improve soil retention.

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